Breakthrough

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Large Slag Replacements Demonstrate Viability in Concrete Mixes

Business Issue

Large placements of ordinary portland cement produce high temperatures as they cure. This in turn can result in cracks. Controlling curing temperatures is particularly challenging in bridge applications. For years the construction industry has used ground granulated blast furnace slag (GGBFS) as a replacement for ordinary portland concrete cement (OPC) to lower curing temperatures. However, MoDOT specifications only allowed low levels of blast furnace slag in concrete mixes. Higher concentrations warranted further investigation for strength and durability.

Creve Coeur Memorial Bridge

Background

GGBFS is a by-product of the iron production process, and consists mostly of calcium silicates and aluminosilicates. This cementitious material has been touted for both its strength and durability enhancing characteristics when used in concrete. Ground granulated blast furnace slag also has a lower heat of hydration and, hence, generates less heat during concrete production and curing. As a result, GGBFS is a desirable material to utilize in mass concrete placements where control of temperature is an issue. Percentage replacements by weight of GGBFS for cement have ranged from 10 to 90%.

Approach and Discussion

MoDOT teamed with the University of Missouri-Rolla to conduct a study of the strength and durability of GGBFS concrete mixes [1]. The field study was the substructure of the Creve Coeur Memorial Bridge as part of the Page Avenue Extension project in St. Louis County, Missouri. At the time of the project, Section 501 of the Missouri Department of Transportation standard specifications allowed the use of GGBFS at a maximum of 25% replacement for Type I or II cement. However, because of its low heat generating characteristics, GGBFS was approved for use at a 70% replacement of Type II cement. The determination and evaluation of the strength and durability characteristics of the GGBFS mixes used in the Page Avenue project provide both documentation of such characteristics and information for future incorporation of GGBFS in MoDOT concrete construction.

[1] Richardson, David N., University of Missouri-Rolla, (2006). Strength and Durability of a 70% Ground Granulated Blast Furnace Slag Concrete Mix. Report OR 06-008, Missouri Department of Transportation, Jefferson City, MO, USA.

The goals for the use of GGBFS in the Creve Coeur Bridge were to:

1) Lower the heat-of-hydration in the mass concrete footings and piers to reduce excessive temperature differentials, therefore achieving a reduction in cracking.
2) Achieve levels of ultimate strength, workability, and durability comparable to conventional mixes.

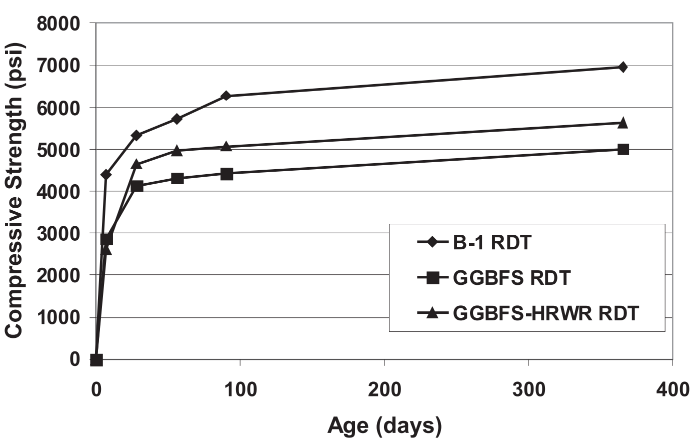
Table 1 – Concrete Mix Designs (Field)

Material	B-1 Mix	GGBFS Mix	GGBFS with HRWR Mix
Grade D crushed limestone (lbs/cy)	1841	1743	1780
Class A sand (lbs/cy)	1155	1170	1185
Type I cement (lbs/cy)	630	0	0
Type II cement (lbs/cy)	0	189	189
GGBFS (lbs/cy)	0	442	442
Water (lbs/cy)	252	264	253
Air entraining agent (oz/sack)	0.91	2.83	2.94
HRWR (oz/sack)	0	0	4.78

The study was divided into two phases. The first involved the sampling and testing of the field-produced concrete for compressive strength (AASHTO T 22-97), freeze-thaw durability (AASHTO T 161-97), rapid chloride permeability (AASHTO T 277-96), and salt scaling (ASTM C 672-92) and, air-void analysis (ASTM C 457-98). The second phase involved laboratory experimentation undertaken to clarify the effects of job cementitious materials on compressive strength.

Fig. 1 shows the average strength gain for each mixture type field-produced. As expected, the GGBFS mixes exhibited slower strength gains at early ages (7 days). This behavior can be explained by the slower pozzolanic reaction of the slag compared to normal portland Type I cement. Also, the slag mixes contained Type II cement, which also typically exhibits lower early strengths. However, results at 90 and 365 days show that the strength of the slag mixtures remained below the OPC (B-1) mix. This outcome was further investigated in the second phase of the study.

Fig. 1-Average compressive strength of all field mixes.



UMR researchers hypothesized that the difference in strengths between the B-1 and the slag mixes may have been due to an insufficient reaction between the slag and the Type II PC. Both the Type II PC and the slag had low amounts of activators, such as alkali and sulfate, which typically function as activators of the slag. Thus, the total available amount of activators in the system may not have been sufficient to fully utilize the potential of the slag. The hypothesis was tested through a series of mortar mixes tested for compressive strength. Certain of the mix combinations reflected the job mix designs: 630 lbs/cy total cementitious materials (TCM), zero and 70% slag, and 0.41 w/cm.

Conclusions

- **Compressive strengths of the 70% GGBFS-Type II PC field mix at all ages up to one year were about 2000 psi lower than the plain Type I PC mix.** The addition of a high range water reducer (HRWR) to the slag-PC mix narrowed the difference to about 1300 psi.

- **When using the same PC type for both the control and slag-PC laboratory mixes, all slag-PC mixes had greater strengths than the plain PC mix.**

- **For slag-PC mixes to obtain strengths equivalent to Type I PC mixes, THE DATA SUGGESTS THAT sufficient activators need to be present to activate the slag.**

- **Slag proportions of 40 to 60 % appear to be the optimum level for highest strength development.**

- **High slag content mixes can achieve typical specified strengths under proper circumstances.**

- **Freeze-thaw durability was lower for the slag-PC field mixes than the plain PC field mix.** However, under optimum wet plus dry curing periods, the slag-PC mix Durability Factors approached that of the plain PC mix.

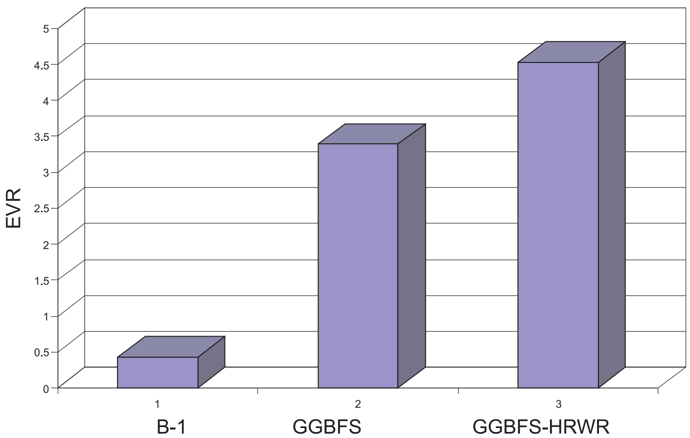
Table 2-Minimum, maximum and median Durability Factors

Mix	DF, min.	Curing Mode, min. (days)	DF, max.	Curing Mode, max. (days)	DF, med., all methods
B-1	94*	35 wet	94*	35 wet	94
GGBGS	58**	35 wet	86**	28 wet + 7 dry	78
GGBFS-HRWR	42***	35 wet	90***	56 wet + 7 dry	48

- **Rapid chloride permeability test values were significantly lower for the slag-PC field mixes compared to the plain PC mix.** Both slag-PC mixes were rated as "low", while the plain PC mix result was "high."

■ **The plain PC field mix had good salt scaling resistance. Both slag-PC field mixes exhibited significantly greater laboratory-induced salt scaling.**

Fig. 2-Results of salt scaling testing



■ **The air void systems of the plain PC and both 70% slag field mixes were similar.**

Recommendations

■ **High-slag content concrete mixes should continue to be considered for future projects, providing that certain conditions are met.**

- The specifications should address only those parameters that are of interest, such as strength, freeze-thaw durability, salt scaling resistance, permeability, and the air void system. Specifications for exterior concrete should be tailored to the environment and the extent and manner in which the structure will be exposed (drainage considerations). The level of required strength should be ascertained, as opposed to a comparison to a non-slag mix.
- Prior to construction, careful attention should be paid during the mix design phase to the actual job materials and proportions that will be used in the mix.

■ **The curing regime for freeze-thaw durability (ASTM C 666) testing for slag mixes should be finalized.**

■ **For slag mixes that will be subjected to deicing salt environments, the most realistic type of salt scaling test/ specification should be adopted.**

■ **For low heat applications using high slag proportion mixes, choice of PC type and level of slag replacement should be made after appropriate trial mixes are analyzed.**

■ **Levels of acceptable Durability Factors for different applications (bridge decks, substructures, pavements, etc.) should be adopted.**

For More Information

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